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LICK

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THE LICK OBSERVATORY ECLIPSE EXPEDITIONS OF JANUARY, 1889, DECEMBER, 1889, AND OF APRIL, 1893.

BY EDWARD S. HOLDEN.

The LICK Observatory is about to print Professor SCHAEBERLE'S report of his observations of the total solar eclipse of 1893 in Chile. This is, then, a favorable time for giving in one place, and in brief, the chief results obtained by the three eclipse expeditions sent out from the LICK Observatory.

When the LICK Observatory was opened for work in June, 1888, it was fully provided with fixed instruments, but its photographic equipment consisted of small cameras only.

The total solar eclipse of January 1, 1889, which was visible in California, had to be observed with such apparatus as was then available; and it was not practicable to obtain photographic cameras of large aperture and relatively short focus at that time. It was therefore determined to make the chief work of the LICK Observatory party in the field (at Bartlett Springs) spectroscopic in character. At the eclipse of May, 1883, Professor HASTINGS (of Yale University), observing with a special spectroscopic apparatus, devised by himself, had compared the spectra of the opposite limbs of the Sun, and had come to the conclusion that the solar corona was, in great part, a diffraction phenomenon, and therefore that the corona had no objective existence.*

As Professor HASTINGS' conclusions had not been generally accepted, and as his observations had never been verified or disproved, it was arranged that Professor KEELER, chief of the LICK Observatory party, should employ a duplicate of the apparatus devised by Professor HASTINGS, and should repeat the observations made at the 1883 eclipse.

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* *Memoirs* of the National Academy of Sciences, Washington. Vol. II, 1883, page 102, *et seq.*

The results of Professor KEELER are given in the Report on the Observations of the Total Eclipse of the Sun of January 1, 1889, page 31 *et seq.* His deductions from the spectroscopic observations alone are (*op. cit.* page 49): "We must conclude that the coronal outlines and details are altogether independent of the Moon's position on the Sun, and their objective existence is rendered extremely probable. It would be reduced to a certainty by the undoubted observation of the limb of the Moon nearest the Sun when entirely clear of his disc, since the Moon could only be visible under these circumstances by contrast with a bright background on which it was projected, in which diffraction could have no part." Precisely this observation was recorded on two negatives taken by Mr. E. L. WOODS, an amateur photographer, *before the beginning of totality.** These negatives are now at the LICK Observatory.

The observations of Professor KEELER, in connection with those of Mr. WOODS, conclusively decided the question proposed for solution. The corona is not, in the main, a phenomenon due to diffraction; it has an objective existence.†

The spectroscopic observations made by Professor KEELER also established the very important fact that the observed length of a coronal line at an eclipse is no index of the depth of the corresponding gas in the solar surroundings.‡

We may then consider the Sun to be surrounded by comparatively shallow envelopes, and great theoretical difficulties are thus removed; as, for example, questions connected with the unretarded passage of comets very close to the Sun's surface.

The meagre photographic equipment of the Observatory did not promise the excellent results which were, in fact, obtained in this department. These results were, in great part, due to the instructions to photographers distributed from the Observatory, which were followed by our own party and by many amateurs. The instructions strongly recommended very short exposure-times,* and they were based on experiments made here by Professor S. W. BURNHAM on photographing faint contrasts on a bright background (light wisps of cloud near the over-clouded Sun).

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* See the Eclipse Report of January 1, 1889, page 164, etc.

† Visual observations of the phenomenon photographed by Mr. WOODS are reported by General C. W. IRISH. See the Eclipse Report of January, 1889, page 191.

‡ See the Report, page 47.

The Amateur Photographic Association of the Pacific Coast volunteered to send a large party of observers to photograph the eclipse under the direction of Mr. CHARLES BURCKHALTER of the CHABOT Observatory of Oakland. This party carried out a programme which had been previously arranged with Mr. BURCKHALTER at Mount Hamilton. The large number of observers allowed experiments in photographing the corona to take a very wide range, in respect of the kind of plates employed, of the light ratio of the cameras, and of the exposure-times. The very valuable observations of these gentlemen are printed in the Eclipse Report of January, 1889, and most of the negatives made by them were generously presented to the LICK Observatory, and are preserved in its collections. I think there is no case on record of so general and so intelligent a seconding of scientific plans by a society of amateurs. The photographic observations of the eclipse of January, 1889, by our own party and by the Amateur Photographic Association, have afforded a sure basis for all subsequent photographic campaigns undertaken by the LICK Observatory eclipse expeditions. The formation of the Astronomical Society of the Pacific is a direct outcome of the eclipse expeditions of January, 1889.

The photographic work of the LICK Observatory expedition of January, 1889, was done by Professor E. E. BARNARD with small cameras, and with a camera improvised by him from a small portable telescope of 3¼ inches aperture and 48.90 inches photographic focus. By stopping down the latter instrument to an aperture of 1.75 inches, and by taking extreme pains in focusing, and in all the subsequent photographic manipulations, Professor BARNARD obtained negatives of the corona which, notwithstanding their comparatively small size, have no superiors among eclipse photographs up to that date.

The methods of photographic photometry, which were first proposed by Captain ABNEY, F.R.S., and which were in use at the HARVARD College Observatory, were adopted at this eclipse, and have been adhered to at subsequent eclipses observed by parties from the LICK Observatory. The resulting plates have been studied by Professor LEUSCHNER, and their discussion is to form a part of his thesis for the degree of Ph.D.

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* Suggestions for Observing the Total Eclipse of the Sun, of January 1, 1889, page 18.

The photographic photometric measures of this eclipse (and of subsequent eclipses observed by LICK Observatory parties) are provisionally reduced in the Reports, under the assumption that the photographic action on the plate varies directly as the product of the intensity of the light and the time of exposure.

This assumption rested on the authority of Captain ABNEY. Our own trials soon showed that whatever the true law might be, this law was incorrect, and Captain ABNEY'S most recent work does not confirm his earlier conclusions.*

It is very possible that no data of great value can be obtained from comparisons of this kind between the effects of two sources of light of *different spectra* on sensitive films exposed for *different times*. The observations will, however, be continued on the same plan at future eclipses until this point is established.

The negatives of the January eclipse were on a very small scale, and required to be magnified in order to exhibit the manifold detail contained in them. An enlarged drawing made by me from the negatives of Professor BARNARD contains no less than 113 reference numbers to separate features. Besides the detail in the immediate vicinity of the Sun, these negatives showed a very noteworthy trumpet-shaped extension, which can be followed to 77′ from the Sun's centre. This extension is shown on a negative which was exposed for four and one-half seconds, during which time the photographic spreading, or diffusion, of the image in the film would be very small. The negatives secured by the U. S. Naval Observatory expedition under my charge in Colorado (July 29, 1878) were exposed about twenty seconds and showed an extension of 50′ from the Moon's limb; those of the British and French expeditions to Caroline Island (May, 1883) were exposed for two and five minutes, respectively, and show extensions of about 60′ from the limb.

At the California eclipse this extension was excellently shown on negatives made by the parties sent from the LICK Observatory, from the HARVARD College Observatory, and from the WASHINGTON University of St. Louis, as well as on many of the negatives secured by the members of the Amateur Photographic

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* *Publications* A. S. P., Vol. VI, 1894, page 67.

Association of the Pacific Coast. Among the latter negatives those of Messrs. IRELAND and LOWDEN were especially successful, as they showed the coronal extensions out as far as 135′ and even 165′, with exposures of 10 (21 and 41) seconds. The reality of this extension has been doubted by various astronomers. It was, however, photographed by Professor SCHAEBERLE at the eclipse of April, 1893, where it extends 190′ east and 246′ west of the Sun's center, with an exposure of four seconds. It must therefore be accepted as a real feature. If the Mechanical Theory of the Corona proposed by Professor SCHAEBERLE be correct, the existence of such an extension is called for by theoretical considerations. In any event, it has a real existence.

The enlarged drawing made from Professor BARNARD'S negatives also brought out in clear relief the fact that the so-called "polar rays" were by no means confined to the poles, but extended all round the disc of the Sun, in the equatorial as well as the polar regions. The excellent definition of the negatives permitted such rays to be traced (for the first time, so far as I know) all through the bright "wings" at the equator. This new result of observation required a new theory to account for it. Its interpretation follows directly from the Mechanical Theory of Professor SCHAEBERLE.

The Report of the Eclipse of January, 1889, contains a number of observations of interest and importance communicated by volunteer observers. Among these, I may point out Dr. LEWIS SWIFT'S observations of *white* prominences around the Sun (*op. cit.*, page 203), thus confirming the results of TACCHINI.* The same phenomenon may have been observed (in part) by General IRISH (*op. cit.*, page 193, line 13, from bottom).

The results derived from the observations of the eclipse of January 1, 1889, made it especially desirable to take advantage of the experience then gained, and to observe the total solar eclipse of December 21, which was to be visible in French Guiana. It was, however, found to be impossible to fit out an expedition to this distant point from the funds annually allotted to the LICK Observatory, and the plan had been reluctantly given up, when Hon. CHARLES F. CROCKER, one of the Regents of the University, generously offered to bear the whole expense of an expedition to South America.

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* *Atti d. Accad. dei Lincei*, 1889, page 472.

On account of the remoteness of the observing station, and the consequent expense, it was decided to make the expedition wholly photographic, and accordingly Professors BURNHAM and SCHAEBERLE were provided with photographic apparatus only. The results of the expedition are given in an octavo volume, issued by authority of the Regents of the University in 1891, viz: "Reports on the Observation of the Total Eclipse of the Sun, December 21–22, 1889," etc. The weather at the eclipse was not entirely favorable, but excellent negatives were secured by both observers with various instruments.

The most important outcome of this expedition is contained in Part III of the report above mentioned. It is A Mechanical Theory of the Solar Corona, by Professor SCHAEBERLE, whose statement of his conclusions is as follows (*op. cit.*, page 48):

"Three well-known facts serve as a basis on which the whole theory rests. They are:

"(1) *The eruptions of the Sun's surface are most active and numerous in the spot-zones.*

"(2) *The Sun rotates about an axis passing through its center.*

"(3) *This axis is inclined to the plane of the Earth's orbit at an angle of about* 82¾°.

"As the present theory also enables one to reproduce, graphically, practically all the phenomena observed during a total eclipse of the Sun, and as the graphical construction is in strict accordance with known mechanical laws, the following brief statement of the theory may be properly made here:

"The theoretical corona is caused by light emitted and reflected from streams of matter ejected from the Sun, by forces, which, in general, act along lines normal to the surface of the Sun; these forces are most active near the center of each Sun-spot zone.

"Owing to the rotation of the Sun, the streams of matter will not lie along normals, since the angular velocity of different portions of a stream grows less as the distance from the Sun increases; in other words, the streams are of double curvature. Each individual particle of the stream, however, describes a portion of a conic section, which is a very elongated ellipse, so long as the initial velocity is less than 383 miles per second (assuming that the Sun's atmosphere, as shown by various observations, is exceedingly rare).

"Certain variations in the type of the corona admit of an exceedingly simple explanation, being principally due to the change in the position of the observer with reference to the plane of the Sun's equator. *According as the observer is above, below, or in the plane of the Sun's equator, the perspective overlapping and interlacing of the streamers cause the observed apparent variations in the type of the corona.*

"The general direction in which these ejective forces act will be along radii. There may, of course, be numerous particular exceptions to this general direction.

"Similarly, since observation shows that certain solar motions are apparently confined to special regions, which are symmetrically situated with reference to the axis of rotation of the Sun, we are evidently justified in assuming that the forces which cause these motions are, in general, uniformly distributed around each circle of latitude, since there is no *a priori* reason why, in a highly heated rotating mass of matter, the solar activity should be confined to any particular circles of longitude. There may, of course, be particular exceptions to a uniform distribution of the forces.

"As the exact nature of the atmosphere surrounding the Sun is unknown, and as its extreme rarity has been demonstrated by various observations, the heliocentric motions of all particles exterior to the Sun's visible surface will be considered to be unimpeded by solar atmospheric resistances."

The theory announced in the general terms just given was put into a mathematical form by its author and was subsequently compared with, and found to agree with, the results of observation at all previous eclipses, including those which had been photographed by LICK Observatory parties.

A very favorable opportunity for testing this mechanical theory of the corona presented itself in the total solar eclipse of April 16, 1893, which was visible in Chile. By the aid of a timely grant of money from Mrs. PHŒBE HEARST, of San Francisco, it was possible to provide for the expenses of an expedition from the LICK Observatory under the charge of Professor SCHAEBERLE. The services of several volunteer aids were secured by him, and the expedition, which was wholly photographic, was eminently successful in every respect.

The plans for the photographic work were made by Professor SCHAEBERLE, in particular those for utilizing the 40-foot photographic objective of the photo-heliograph. The magnificent large-scale photographs (on 18 x 22 plates) thus secured have opened a new era in eclipse photography. They permit very small features of the corona and of the prominences to be represented on a scale sufficiently large to make them intelligible. Some of these features also exist in the enlarged *drawings* made by Mr. WESLEY from the negatives of the eclipse of 1871; but while they were (partly) represented, they could not then be completely interpreted.

It is hoped to secure similar large-scale photographs on the same plan and with the same instrument at the total solar eclipse of 1896 in Japan. At the same eclipse, it is also hoped to renew the spectroscopic investigations of the corona, which have been neglected since January, 1889, for the very simple reason that our available funds were not sufficient to provide the necessary expenses of another observer and instrument.

The eclipse negatives secured by Professor SCHAEBERLE in Chile showed a cometary form to which he called attention at the Astronomical Congress of the World's Fair in August, 1893.*

In May, 1894, we received, through the kindness of the Eclipse Committee of the Royal Astronomical Society, copies of the eclipse negatives taken by the British expeditions to Brazil and Africa, respectively. The eclipse-comet is found on both sets of plates (as well as on the plates of the HARVARD College Observatory expedition in Chile).

One of the incidental results of the expedition is, then, the discovery of a bright comet, which was seen at no observatory, and which would, therefore, have been lost had it not been for these plates. It should receive the designation of the "Eclipse-Comet of April 16, 1893," according to the scheme of nomenclature adopted by Professor KRUEGER in the *Astronomische Nachrichten.*

The most important conclusion reached by Professor SCHAEBERLE, at the eclipse of April, 1893, is that the photographs confirm his mechanical theory of the solar corona, announced in 1890. In his own words:

"The coronal structure of this eclipse is apparently governed throughout by a single simple law, viz: The matter is arranged along portions of elliptical streams, one focus of the ellipse being at the Sun's center, * * * the origin of these streams being, in the main, confined to the Sun-spot regions."

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* *Publications* A. S. P., Vol. VI (1894), pages 144, 237.

The areas within the Sun-spot zones, projections from which produced the corona of April, 1893, have been located by Professor SCHAEBERLE. They are six in number; and outbursts of solar matter from them moving in ellipses will account for all the (main) features of the coronal prominences, wings and gaps as exhibited in the photographs.

"To sum up the results of the study relating more particularly to the corona of April 16, 1893, the following conclusions are arrived at:

"(1) All visible matter exterior to the Sun's surface is apparently in rapid motion, the path described corresponding to one of the conic sections. The so-called stationary prominences are probably stationary as to the general form only, the matter in the same being in rapid motion, which remains visible so long as the density is sufficiently great. I have carefully compared the eclipse photographs taken with the 40-foot telescope on April 16, 1893, with the best spectroscopic observations accessible (both visual and photographic) taken of the uneclipsed Sun on the same day, and the result, briefly stated, is that while the coarser features of the Sun's surroundings are shown in spectroscopic observations of the uneclipsed Sun, *the finer and essential details are wanting.*

"(2) All coronal streamers are apparently composed of matter ejected from the Sun with great velocity. This matter moves in one of the conic sections, and has its origin mainly in one of the Sun-spot zones. In general, when seen at the Moon's outline, in projection, any given portion of a coronal streamer is in reality at a great distance from the Sun.

"(3) A so-called wing of the corona is apparently produced by the overlapping in projection of many streams of matter coming from two (or more) different centers of eruption; the direction of the axis or greatest extent of the wing being in general roughly at right angles to the line joining the two eruptive centers. A necessary consequence resulting from the formation of wings is the formation of 'gaps' in the corona, a 'gap' being the less dense area between two adjacent wings.

"In conclusion, these investigations seem to demonstrate that, so far as the eclipse of April, 1893, is concerned, there is no evidence that either electricity or magnetism has anything to do with the arrangement of coronal matter in the Sun's neighborhood. A re-examination of the photographs of other eclipses of which the observatory has copies leads to the same conclusion, viz : there is no necessity of introducing either electrical or magnetic forces to account for any of the coronal forms, as each true stream-line can practically be made to lie on the arc of a conic section having the sun at the focus. The abnormally curved streamers, usually forming wing-boundaries on the smaller scale photographs of the present eclipse are, on the larger negatives, shown to be due to the overlapping of different nearly osculating streamers, the individual members, however, can be made to coincide with the arc of a gravitational conic section. It is almost certain that the abnormal outlines recorded for other eclipses are produced in a similar manner."

LUNAR ECLIPSES AND SOME SIMILAR PHENOMENA.

By W. H. S. Monck.

The two most remarkable characteristics of lunar eclipses are the large amount of light which frequently appears on the eclipsed Moon and the fact that the eclipse—the true shadow—is larger than the geometrical shadow. The connection between these two facts has not perhaps been as fully recognized as it ought to be.

No one can doubt that the light which falls on the eclipsed part of the Moon comes from the Sun, and that it does not pass through the solid body of the Earth. Placing the corona out of account for the present therefore, the only explanation is that light, which would otherwise pass outside of the geometrical shadow, has been turned out of its direct course so as to fall within that shadow. This diversion of the light must naturally produce a deficiency at the place from which it has been diverted. And I think there can be little doubt that the cause which diverts the light is the Earth's atmosphere. Bending the rays which pass near the Earth into the geometrical shadow, it naturally leaves a deficiency of light for some distance outside of that shadow. The result is that the eclipsed Moon is at least partially illuminated, while the real shadow becomes larger than the geometrical shadow.